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MACHINING OF BERYLLIUM WITH THE LLNL PRECISION ENGINEERING RESEARCH LATHE

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Lawrence Livermore National Laboratory

March 22, 1985

Machining of Beryllium With the LLNL*

Precision Engineering Research Lathe

Richard J. Foley

Lawrence Livermore National Laboratory

In August 1984, six flat samples of beryllium, which were prepared by Brush-Wellmen Corp. using various pressing and sintering processes, were machined at LLNL on the recently completed Precision Engineering Research Lathe (PERL)[1,2]. The purpose of this study, which was conducted in cooperation with the Hughes Aircraft Corporation and partially funded by that organization, was to determine the optical properties of machined beryllium surfaces when prepared under highly controlled conditions using high quality machine tools and CBN (cubic boron nitrite) cutting tools.

This report will summarize the materials properties, the machining conditions used on the PERL and a comparison of the completed samples using optical measuring techniques and scanning electron microscopy (SEM). The mirror surface reflecting measurements in the IR region are to be made by the group at Hughes Aircraft and will be exchanged with LLNL as a part of this joint technical effort.

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*This work performed under the auspices of the United States Department of Energy by the Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48, in cooperation with and partially funded by Hughes Aircraft Corporation.

PREPARATION OF BERYLLIUM SAMPLES

(Data Prepared by Brush-Wellman Corp., Elmore, Ohio)

Sample #	Billet Identification	Powder Size	Consolidation Method
1	S-65 O.S.	Oversize I-70A	HIP
2	MC 733	Fine Cut I-70A	HIP
3	MC 736	Standard I-70A	HIP(4)
4	2125	Oversize I-70A(2)	VHP-HIP
5	2124	Standard I-70A(1)	VHP-HIP
6	2127	Fine Cut I-70A(3)	VHP-HIP

(1) Standard
(2) Oversize
(3) Fine Cut
(4) HIP -- 1525 F/4 hrs/15 ksi

BERYLLIUM MACHINING CONDITIONS

The six beryllium samples were machined in the Precision Engineering Research Lathe (PERL) shown in Figure 1. All samples were machined dry to avoid any contamination from cutting fluids which may become trapped within the beryllium material.

These samples were machined with a Sumiboron Cubic Boron Nitrate (CBN) tool, BN100 with a 0.005" radius cutting edge, Figure 2. The machining procedure used is listed below:

1) Approximately 0.001" of material was removed from surface to insure material integrity before finish cuts.

2) Two 0.0002 cuts were taken before the finish cut.

3) The final machine cut was taken at a depth of 40 μin using an unused portion of the CBN tool for each test sample. The cut was performed at a spindle speed of 900 R.P.M. and a cross head movement of 0.1 inch/minute.

PRECISION ENGINEERING RESEARCH LATHE (PERL)

LLNL recently completed the design and fabrication of a small, two-axis, ultra-high precision, numerically controlled lathe for the turning of small contoured parts. Single-axis cutting tests, using a diamond tool on a flat copper part, resulted in a surface finish of 0.1 to 0.2 μin R_a(0.5 to 1 μin peak-to-valley. This machine will both increase our production capacity and improve our accuracy capability.

The approach taken on the design of the PERL was fundamentally the same as that used on its predecessor, the Baby Optics Diamond Turning Machine (BODTM), in both cases we attempted to maximize machine stiffness and resonant modes and to minimize sensitivity to temperature fluctuations by (1) minimizing the size of the machine and (2) minimizing the structural loop of the machine by selecting a T-base configuration.

While the configurations of the two machines are similar, we attempted to improve the accuracy of the PERL by utilizing more accurate slides and higher performance servos. Some of the more significant design features of the PERL are shown in Fig. 1 and described below.

Slides and Slide Drives

To obtain the required accuracy and friction characteristics, the two linear slides are supported by 4-in. travel hydrostatic bearings developed at LLNL. Oil was used to pressurize the bearings to provide viscous damping. The deviation from straightness of travel for both slides has been demonstrated to be less than 8 μin in full travel.

Capstan drives were used to provide slide motions to minimize the Coulomb friction in the slide drives. A steel roller, pre-loaded against a steel drive bar by a hydrostatic (air) pad, is driven by a dc torque motor. The drive bar is attached to the slide by a pair of flexures in order to minimize the effects of misalignment of slide straightness. Velocity feedback is provided by a tachometer mounted integrally with the drive motor.

Position Feedback

Position feedback for both slides is provided by interferometers operating at 1 μin resolution. In the case of the x (tool) slide, the consequences of slide angular motion are minimized by locating the laser in line with the tool. On the z-slide, where the effects of slide angular motion on positioning accuracy cannot be measured directly, two interferometers, one on either side of the spindle, are used to provide angular motion data to the computerized numerical control system (CNC), which will correct for the consequent positioning error in real time.

Spindle and Spindle Drive

Both the radial and axial motion error values of the workpiece spindle are less than 1 μin. To obtain the best surface finish possible, we minimized asynchronous (nonrepeatable) spindle motion by driving the spindle directly with a brushless dc torque motor. The motor rotor is cantilevered directly from the spindle rotor, and the motor stator is mounted from the spindle stator. This configuration also served to eliminate separate motor bearings, a potential source of vibration. The brushless dc torque motor was selected because with this configuration most of the heat is generated in the stator, where it can be most easily removed. By enclosing the stator in a finned housing through which we pump temperature-controlled water, the temperature of the spindle and motor are maintained at $68 \pm 0.05^{\circ}F$.

Temperature Control

As mentioned previously, the size of the PERL was minimized to reduce sensitivity to variations in temperature. This, combined with direct cooling of the spindle, the only major heat source on the machine, allowed us to utilize an air-shower temperature control on the machine. This approach was a departure from previous designs for larger machines where liquid shower systems were utilized.

We have built an enclosure around the machine through which we recirculate 600 cfm of air. This system maintains the machine environment at $68 \pm 0.1^{\circ}F$. Thermal drift of the machine has been observed to be less than 5 μin in a 24-h period.

Computer Numerical Control

We developed our own CNC for use on the PERL. The configuration selected is a multi-processor design based on the Intel 8086 and 8087 processors, installed on the Intel Multibus. Features of the CNC include the following:

Programming resolution: 1 μin

Update rate: 2 ms

Feedrates: 0.0001 to 50.0 in/min

Maximum departure: 10 in

THE SPECIMEN MACHINING DATA

For each of the six machined beryllium test specimens, an inspection of the surface finish was performed to determine the average surface roughness. This data is presented in Figures 3 through Figure 8. In addition to this physical inspection, Scanning Electron Microscope (SEM) photos were taken of the surface finish as several different magnifications. This data is presented in Figures 9 thru 14 for the six test specimens.

In addition to the machining conducted under this effort, more recent work was preformed by the Precision Engineering Program and was written up by R. R. Donaldson.[3]

ACKNOWLEDGEMENTS

The author is grateful for the support given to this project and the development of precision machine tools. In particular to D. L. Thompson and his many assistants in the Mechanical Fabrication Division at LLNL for producing PERL. To P. Landon at LLNL and the Brush-Wellmen Corporation for fabricating the beryllium samples and to W. C. Smiley for his efforts in getting the samples machined and inspected.

References

1) Laser Program Annual Report - 1983, Lawrence Livermore National Laboratory Report UCRL-50021, page 2-4 (1983).

2) Energy and Technology Review, July 1984, Lawrence Livermore National Laboratory, page 83.

3) Informal Report, R. R. Donaldson, LLNL PED 84-1, January 17, 1984.

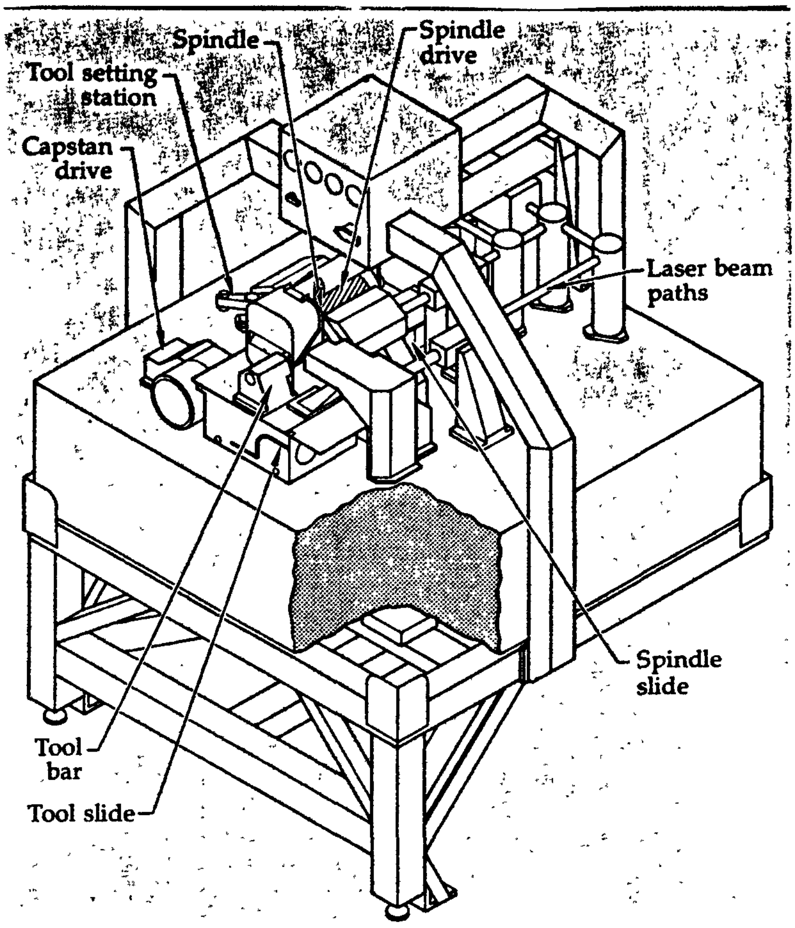

Figure 1 Precision Engineering Research Lathe (PERL) for making small contoured parts.

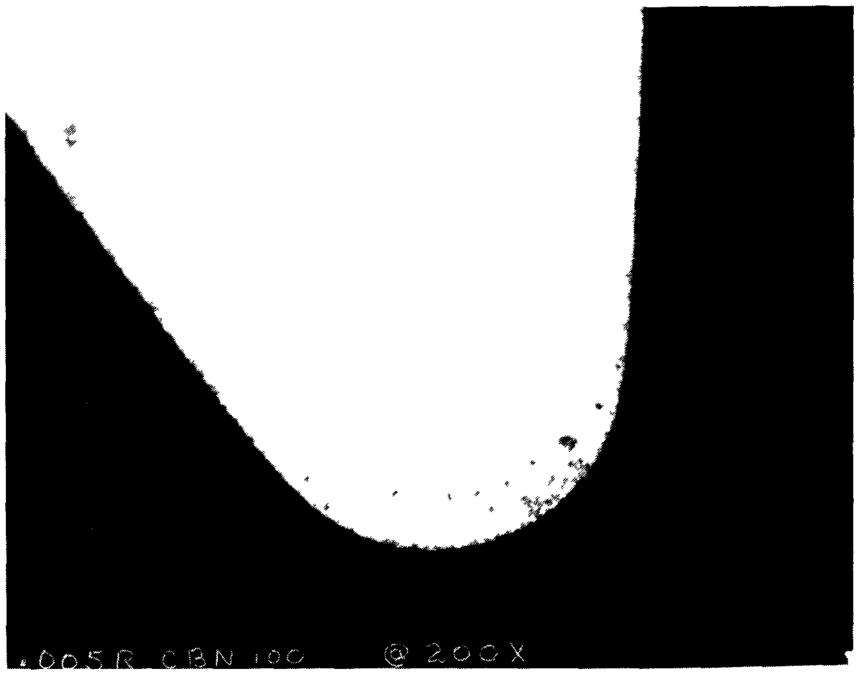

Figure 2 Cubic Boron Nitride (CBN 100) tool used for machining beryllium samples.

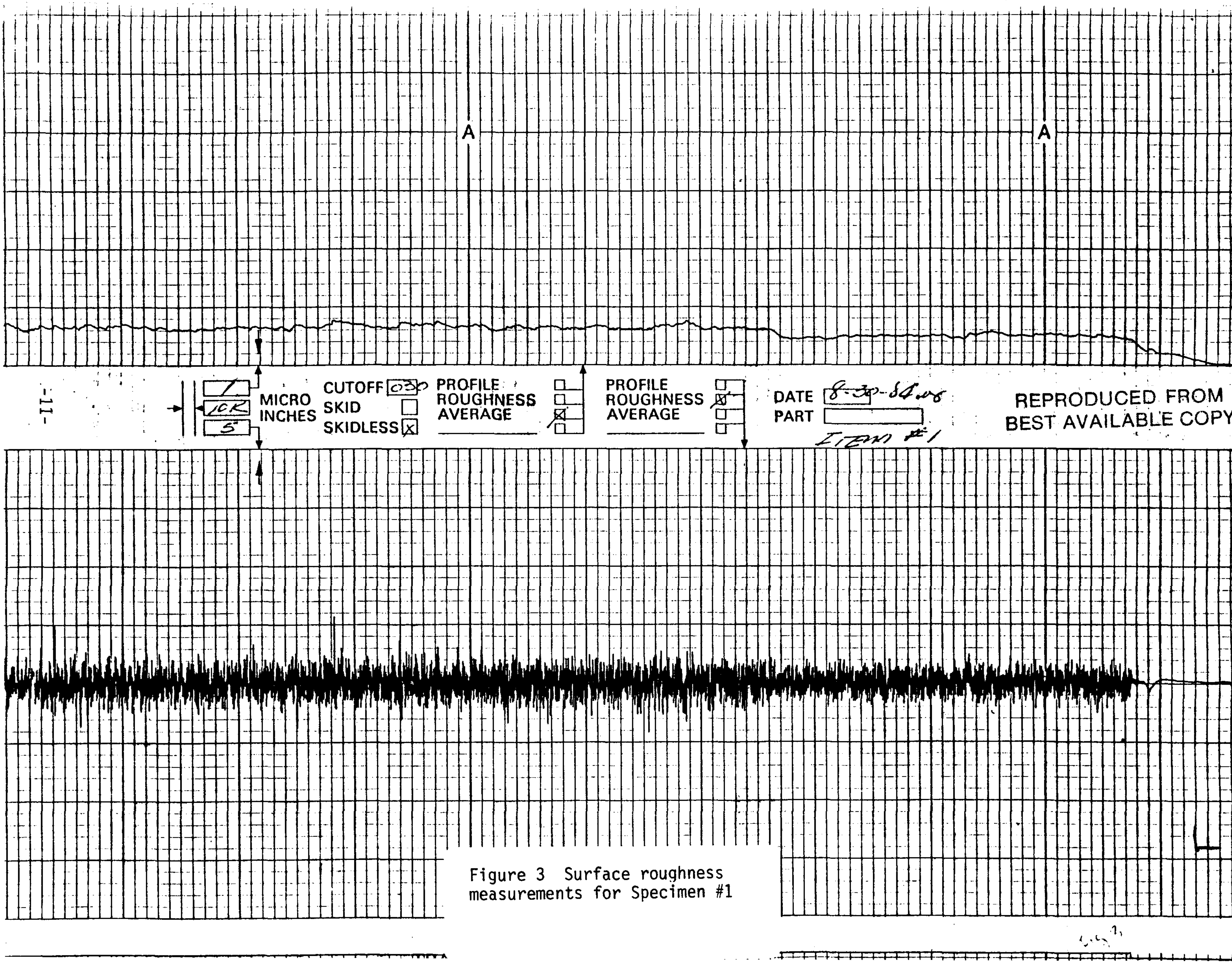

Figure 3 Surface roughness measurements for Specimen #1

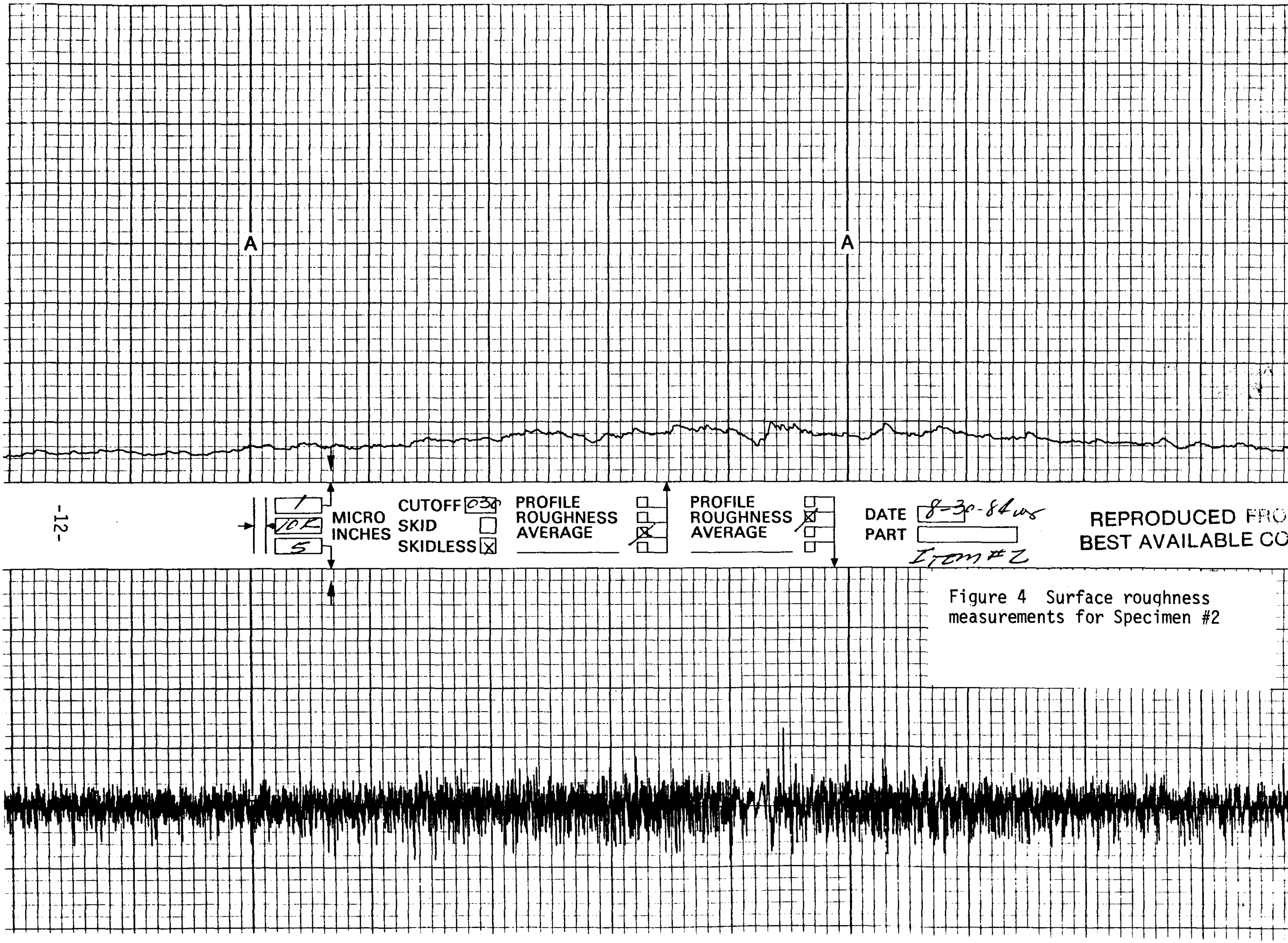

Figure 4 Surface roughness measurements for Specimen #2

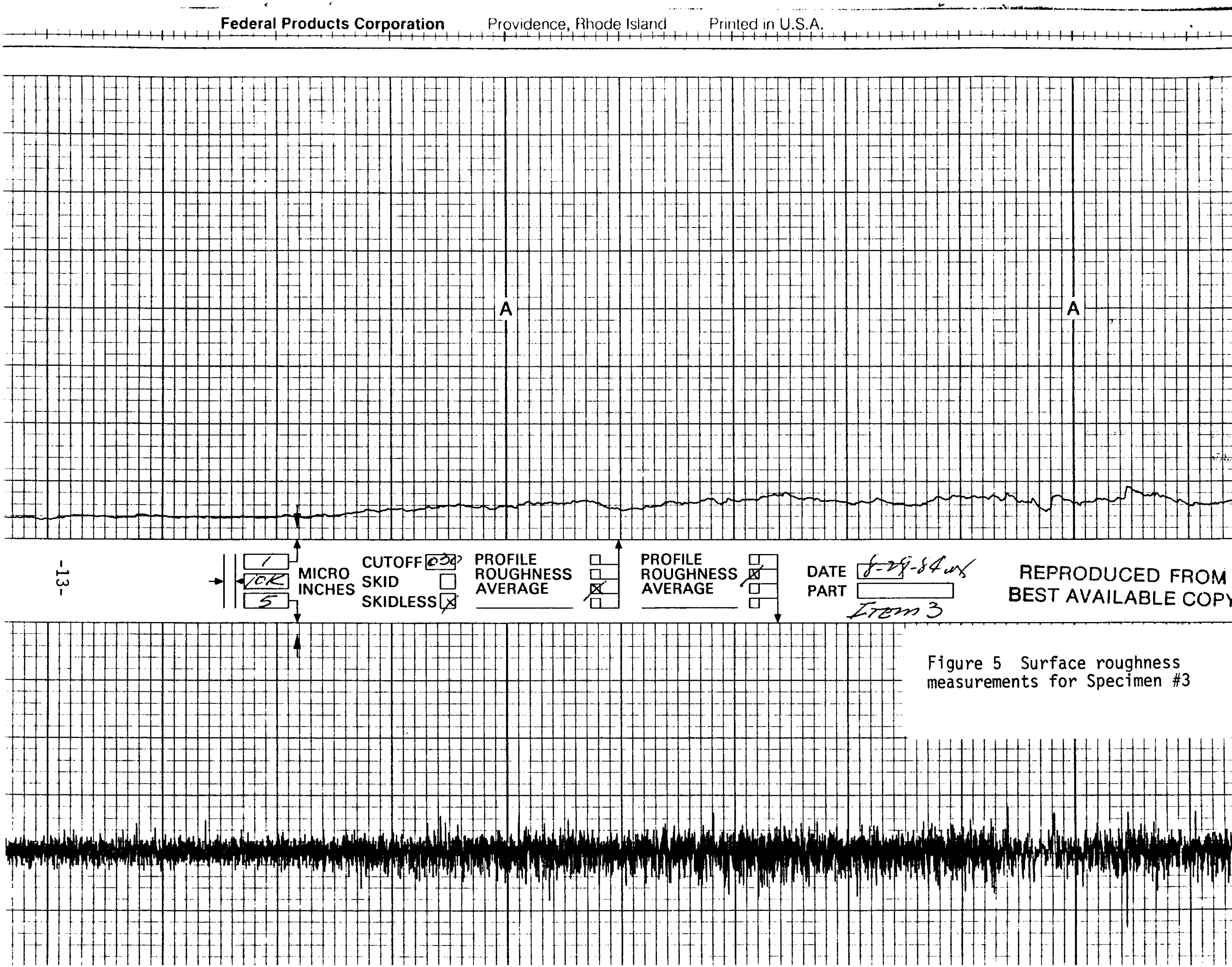

Figure 5 Surface roughness measurements for Specimen #3

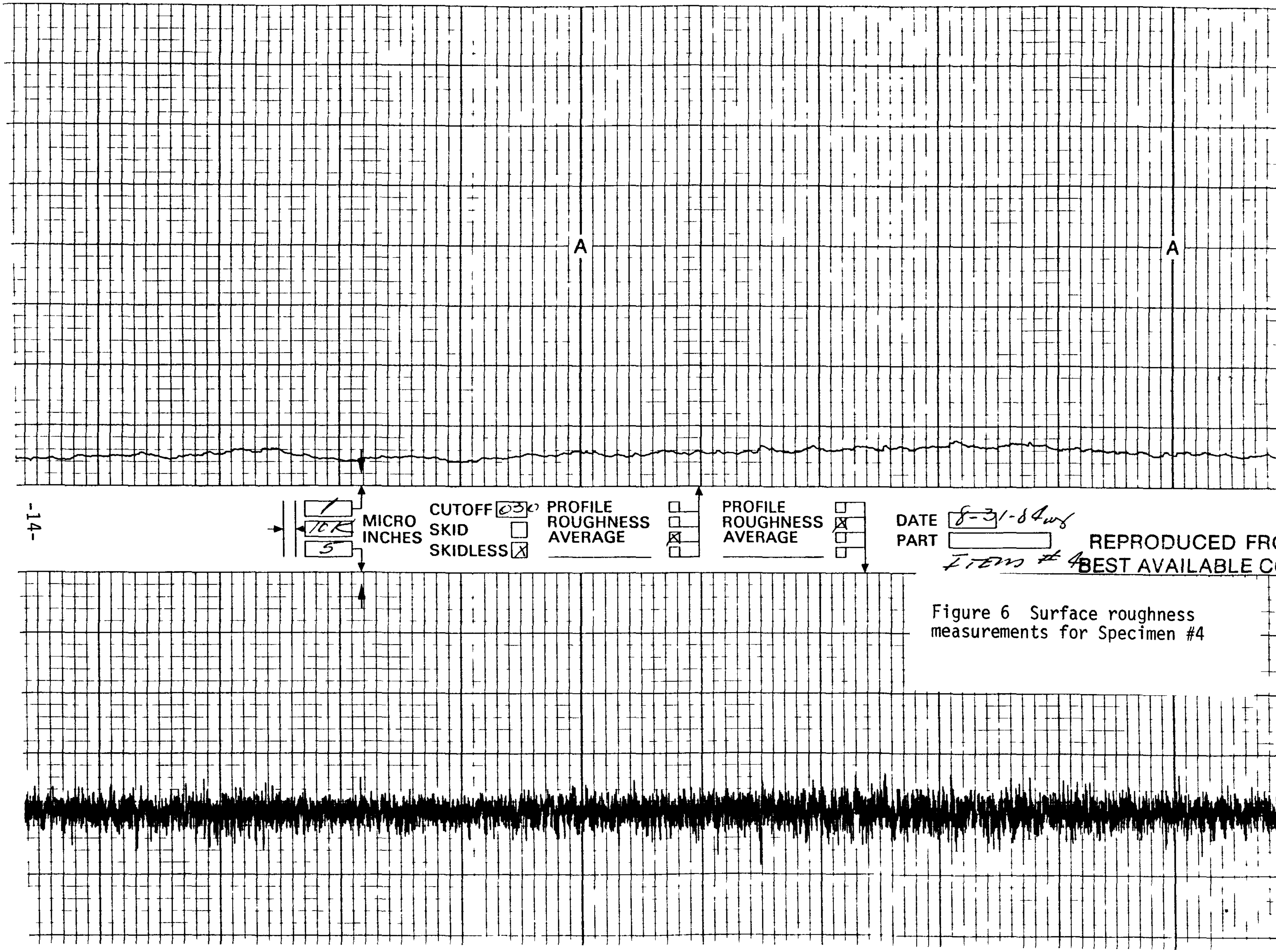

Figure 6 Surface roughness measurements for Specimen #4

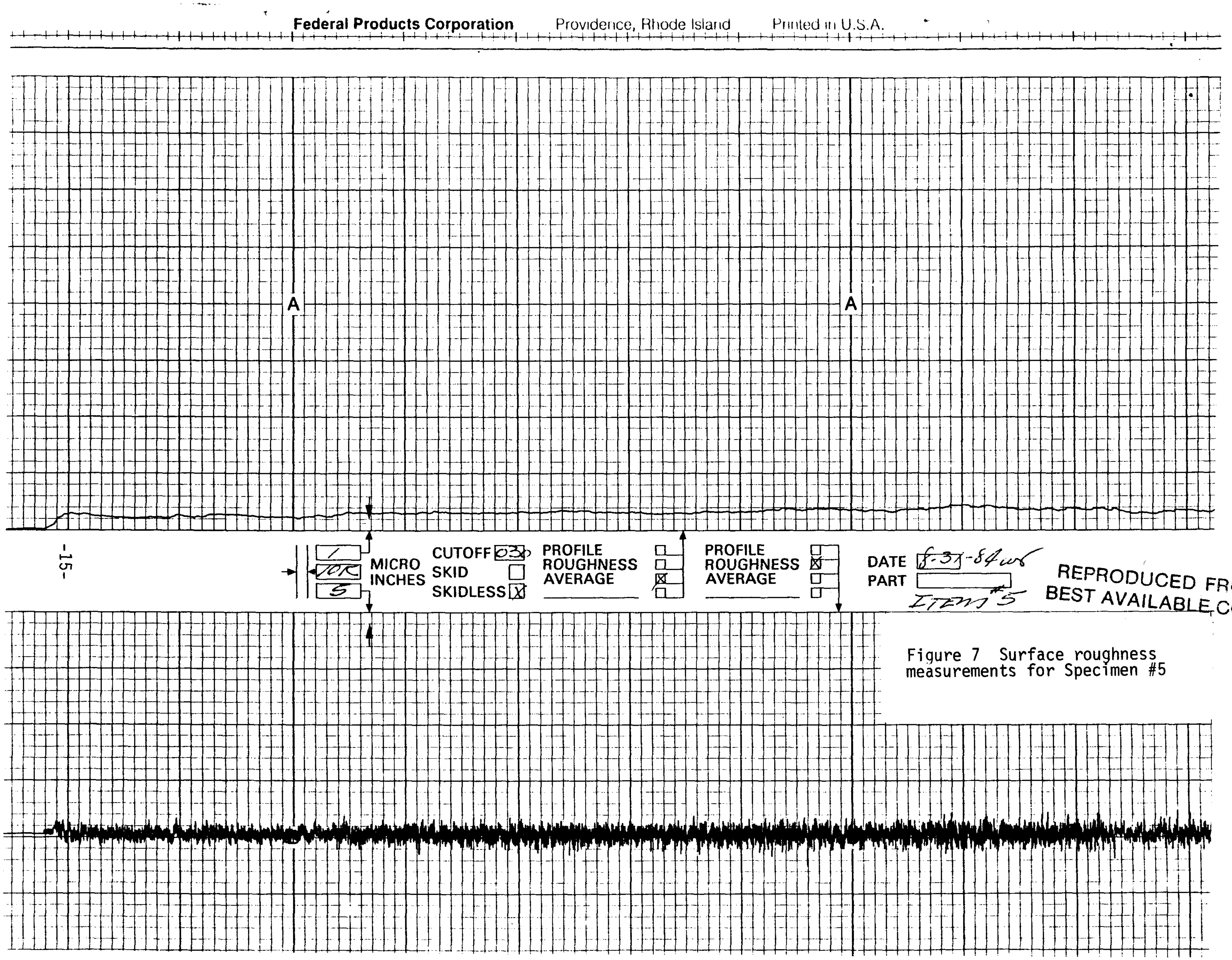

Figure 7 Surface roughness measurements for Specimen #5

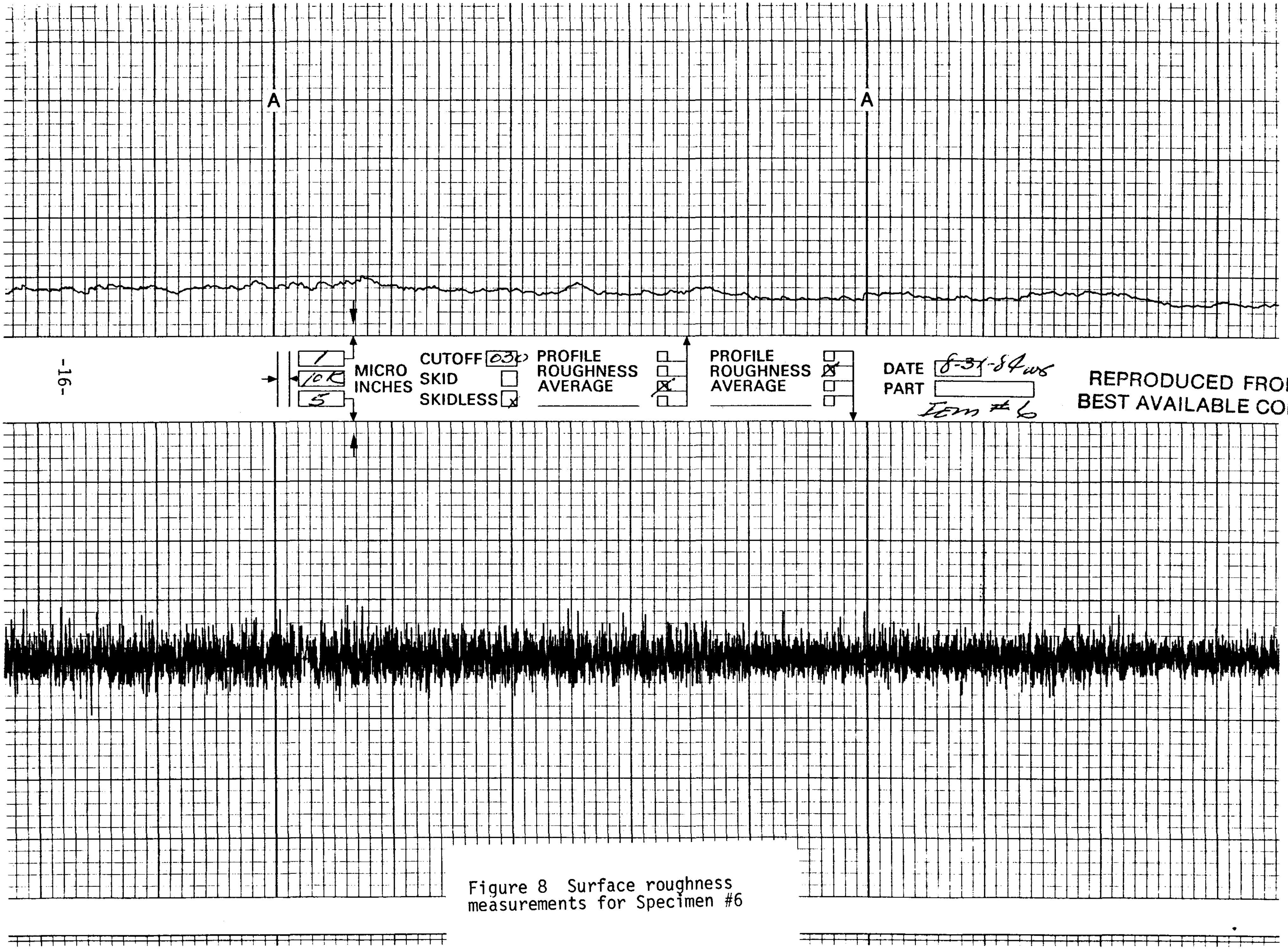

Figure 8 Surface roughness
measurements for Specimen #6

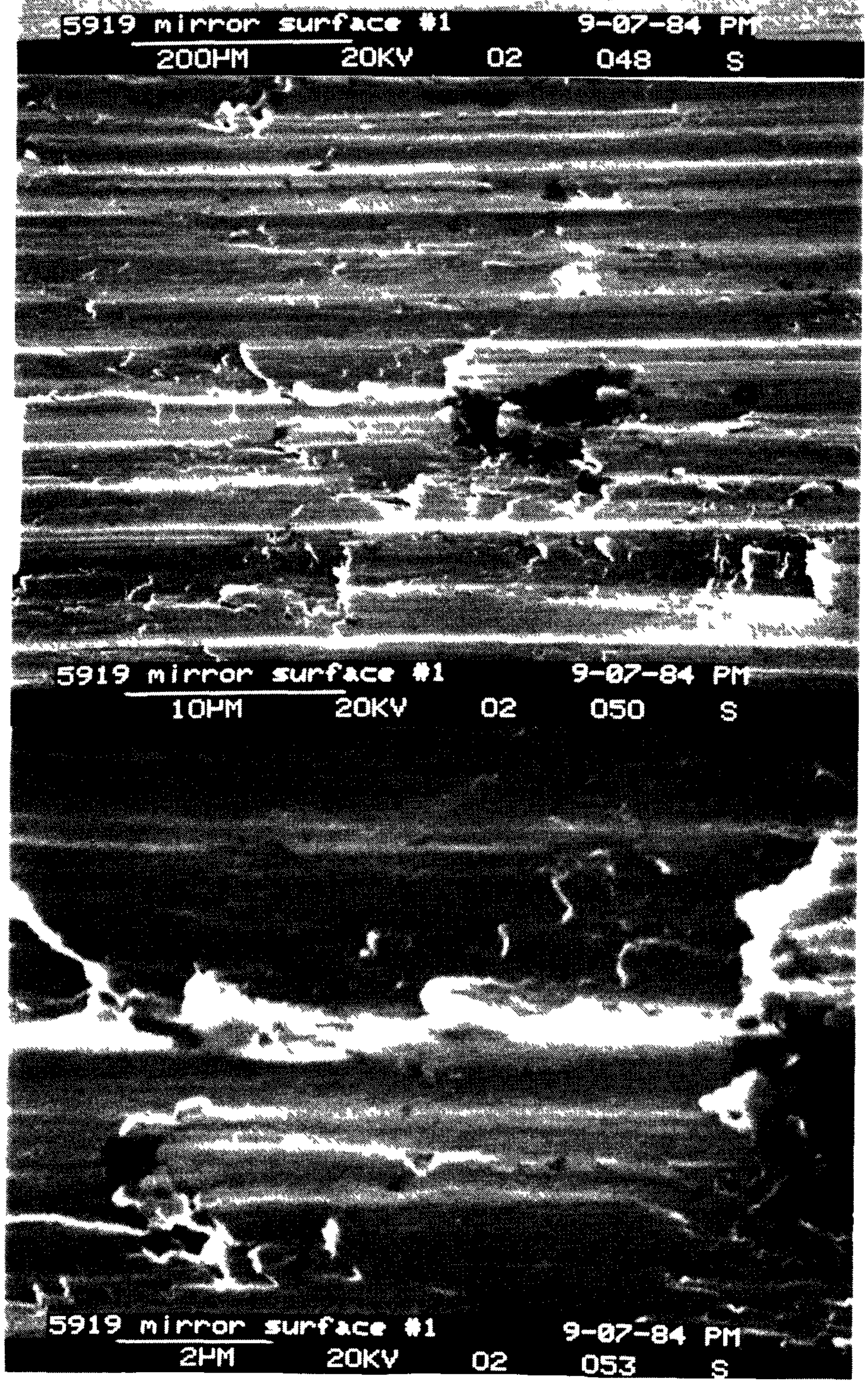

Figure 9 SEM photos of Specimen #1 at magnifications as indicated on photos.

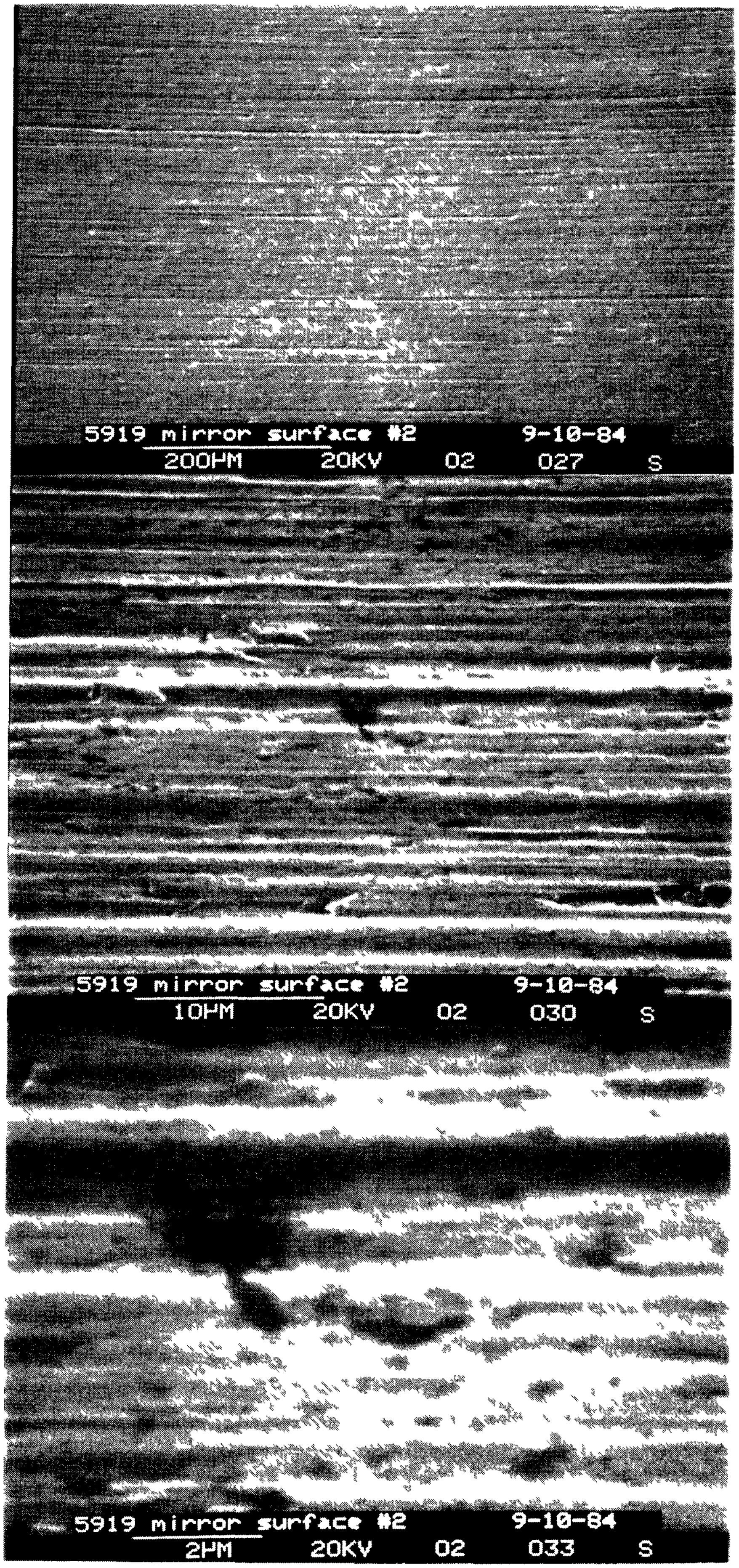

Figure 10 SEM photos of Specimen #2 at magnifications as indicated on photos.

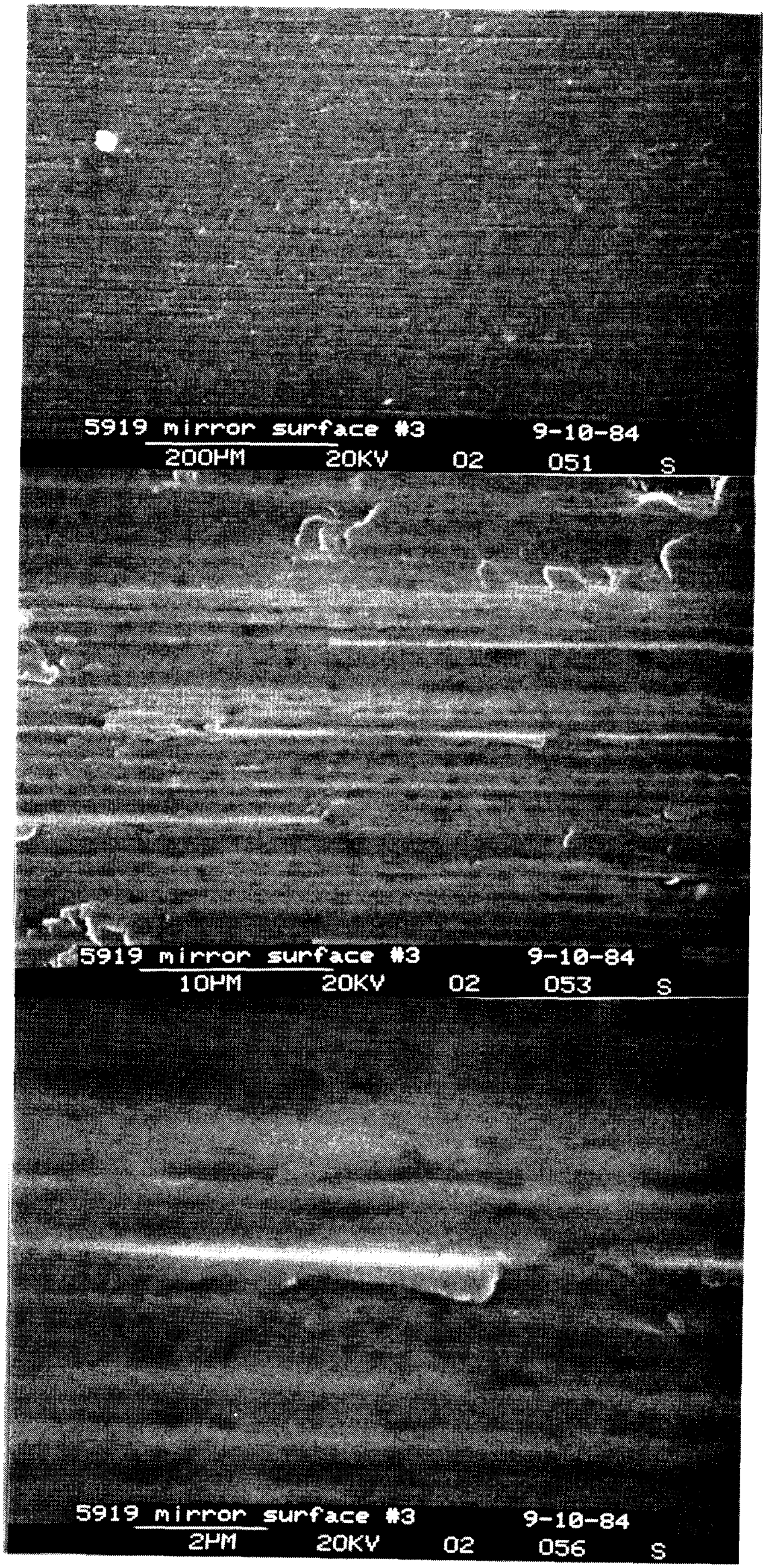

Figure 11 SEM photos of Specimen #3 at magnifications as indicated on photos.

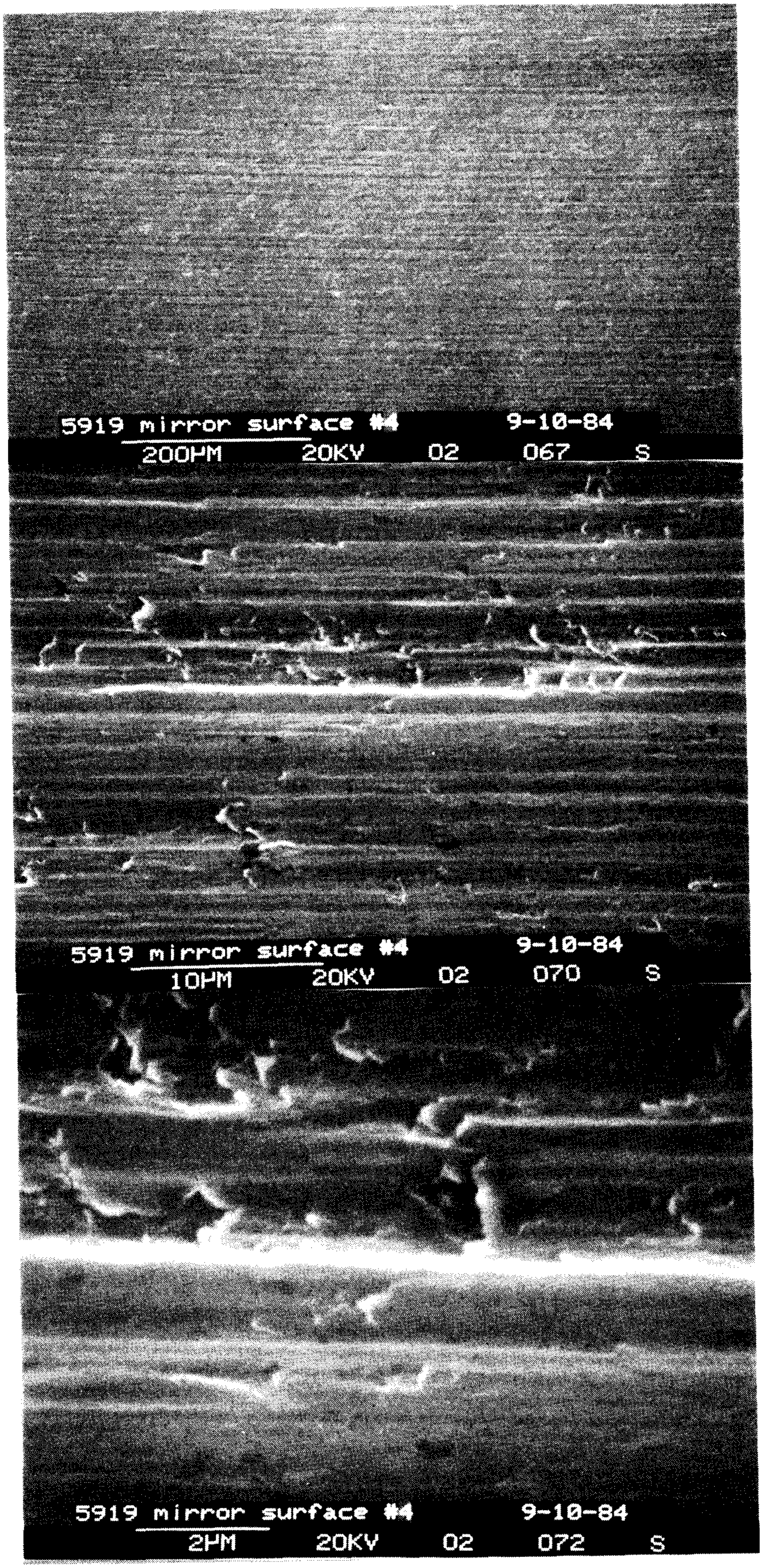

Figure 12 SEM photos of Specimen #4 at magnifications as indicated on photos.

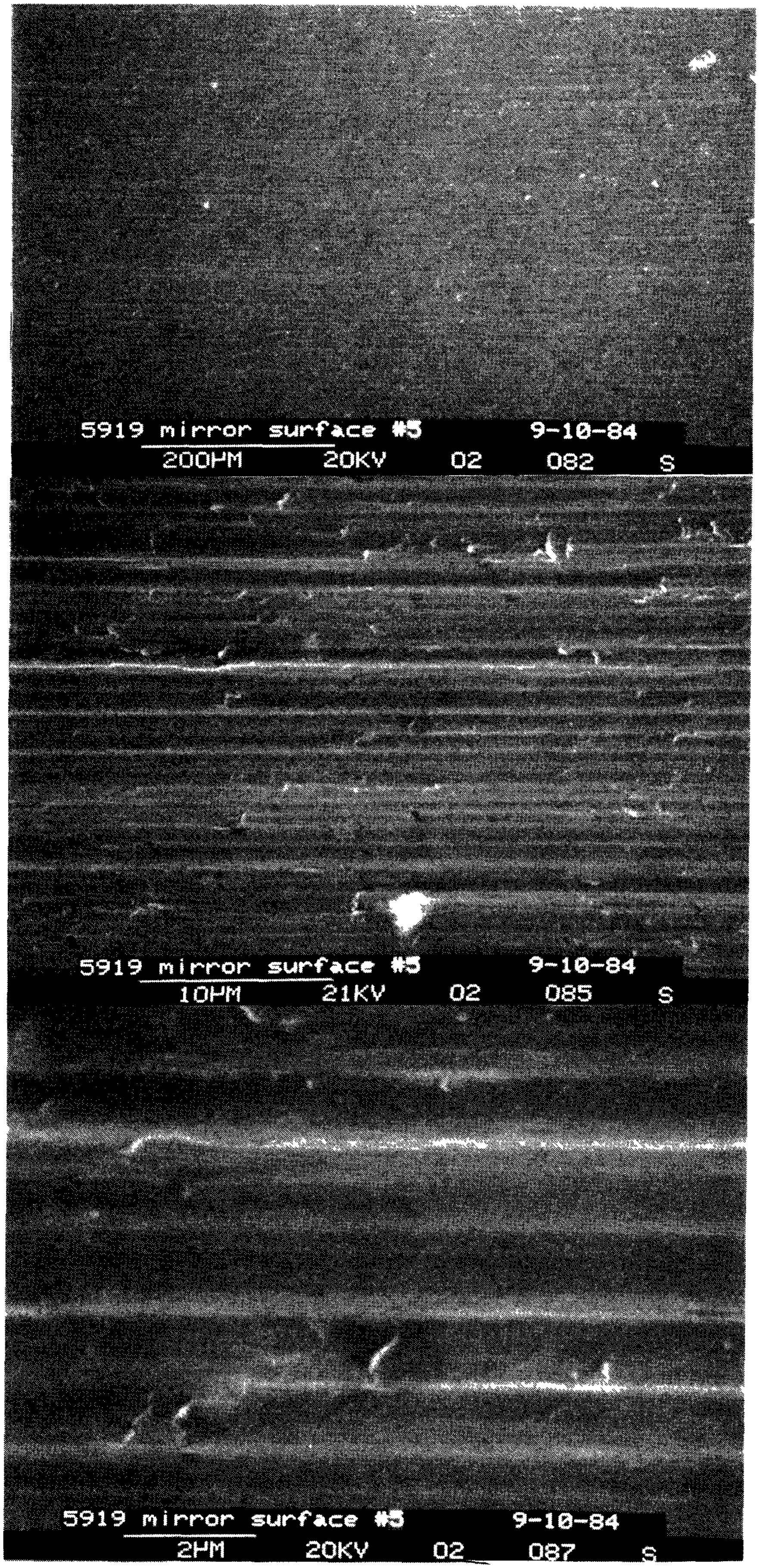

Figure 13 SEM photos of Specimen #5 at magnifications as indicated on photos.

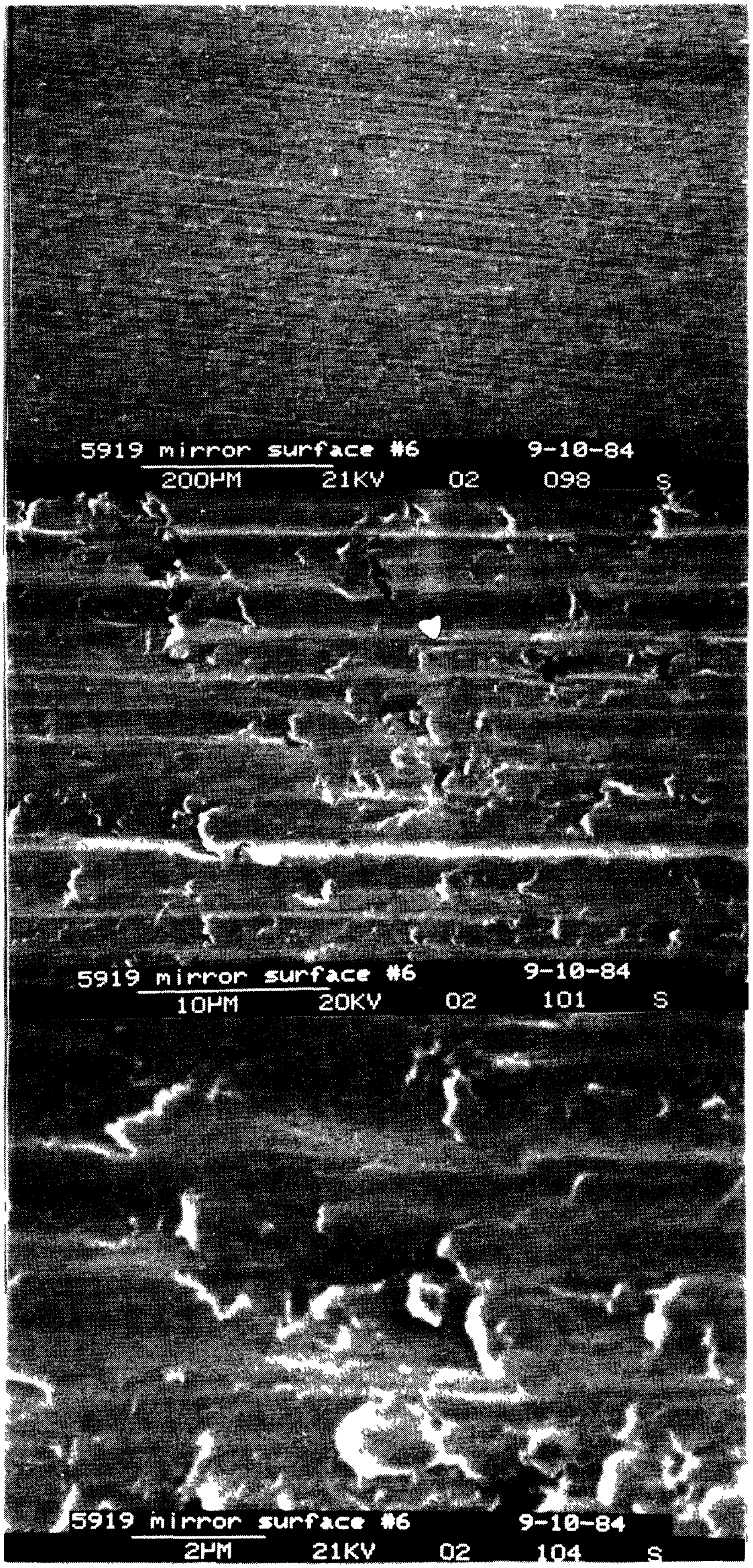

Figure 14 SEM photos of Specimen #6 at magnifications as indicated on photos.

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